

## Fast Optical Photometry of Galaxies: Observations of Short-Lived Flare Events

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**Abstract.** We have monitored two bright galaxies, M85 and NGC 7331, on timescales as short as 0.01 s. In the optical, we discovered an unusual burst coincident with the galaxy M85. We registered a sudden onset with a characteristic time of less than 10 ms with subsequent quasi-exponential decay within approximately 1 s and an amplitude of 2.5 mag in the  $V$  band. In the course of high-speed monitoring with two Crimean telescopes operated synchronously, in both independent instruments we have registered one coincident event occurring in NGC 7331 with a duration of  $\sim 0.6$  s. The amplitudes range from  $\sim 3$  mag to  $\sim 0.3$  mag in the  $U$  and  $I$  bands, respectively. Merging of an intermediate-mass black hole with a small black hole or normal star seems to be the most plausible mechanism responsible for short bursts. Our observations support the hypothesis concerning the existence of intermediate-mass black holes in the centers of galaxies and in dense globular clusters.

### 1. Introduction

We find evidence for variability of some galactic nuclei in the  $UBVRI$  bands on a timescale of tenths of a second. Byrne & Wayman (1975) first carried out a search for optical flashes in the direction of the center of the Galaxy in the early 1970s. This experiment was the first attempt to find an outburst of radiation that may accompany such energetic events as pulses of gravitational waves (GW). Recent studies of coincident events in the gravitational wave detectors Explorer and Nautilus (Astone et al. 2002) give an observed rate around one event per day. Such events correspond to an isotropic conversion of  $0.004 M_{\odot}$  into GW energy for sources located in our Galaxy. This gives us some hope of detecting optical flares from the cores of other galaxies. To detect flares with confidence, it is desirable to carry out a high-speed monitoring by two or more remote telescopes synchronously. We present some preliminary results for two objects, the galaxies M85 (S0,  $B = 10.0$  mag) and NGC 7331 (Sb,  $B = 10.3$  mag). Both of these show very bright inner regions suitable for high-speed monitoring in the optical on timescales as short as 0.01 s with adequate signal-to-noise ratios.

## 2. Observations and Data Analysis

Observations were made in the *UBVRI* bands with the 2-m RCC telescope at Peak Terskol and the Crimean 1.25-m and 50-inch telescopes equipped with high-speed photon-counting photometers. For the majority of these observations, these telescopes were operated synchronously. The nuclei of galaxies were observed with large focal-plane diaphragms (from 26'' to 50''). Second channels of the photometers were used for monitoring comparison stars. In all, we obtained 98 minutes of photometric data sampled at 100 Hz.

### 2.1. Flare Identification

Figure 1 shows an unusual burst in the optical registered while observing the core of the galaxy M 85 during a 1 hour-long run. The burst consists of a sudden onset with a characteristic time of less than 10 ms, with the subsequent quasi-exponential decay within approximately 1 s. Its amplitude amounts to 2.5 mag in the *V* band. No bursts were found in the control star that was observed simultaneously. The maximum flux is equivalent to the flux from a  $V \approx 9.5$  mag star at the zenith. According to the data given by Allen (1973), the expected mean rate at the zenith for meteors brighter than  $V \leq 9.5$  mag in a 39'' field (focal-plane diaphragm) is  $\sim 4.8 \times 10^{-5} \text{ hr}^{-1}$ . Therefore, it is reasonable to assume that a faint meteor did not cause the flare event in M 85. However, we cannot completely rule out that such an event may be produced by some other unknown phenomenon, e.g., by a cosmic-ray event.

During the high-speed monitoring with the two Crimean telescopes operating synchronously, we also found one coincident event occurring in NGC 7331 during a 38 minute-long run. This event corresponds to a short burst with duration of  $\sim 0.6$  s (Fig. 2). The amplitudes range from  $\sim 3$  mag to  $\sim 0.3$  mag in the *U* and *I* bands, respectively.

The detection of transient variations is based on a search for coincidence between the data of different telescopes operating synchronously. Let us convert the light curve using the cumulative Poisson distribution with the mean and current readings  $n_0$  and  $n$ , respectively,

$$P(n, n_0) = \sum_{k=0}^n \frac{n_0^k}{k!} e^{-n_0} \quad (1)$$

which is the probability of obtaining the observational result  $n$ . If a coincidence between two telescopes is due to a real burst, we expect the individual probabilities to be very close to one. The quantity  $SL = 1 - P(n, n_0)$  is the significance level to obtain the observational result  $n$  in the light curve. To calculate the joint significance for  $m$  synchronously operating telescopes, we may write

$$SL_m = -2 \sum_{i=1}^m \ln(SL_i) \quad (2)$$

As noted by Fisher (1970), the statistic  $SL_m$  follows the  $\chi_{2m}^2$  distribution with  $2m$  degrees of freedom. Further discussion of the problem can be found in our paper (Zhilyaev et al. 2003).

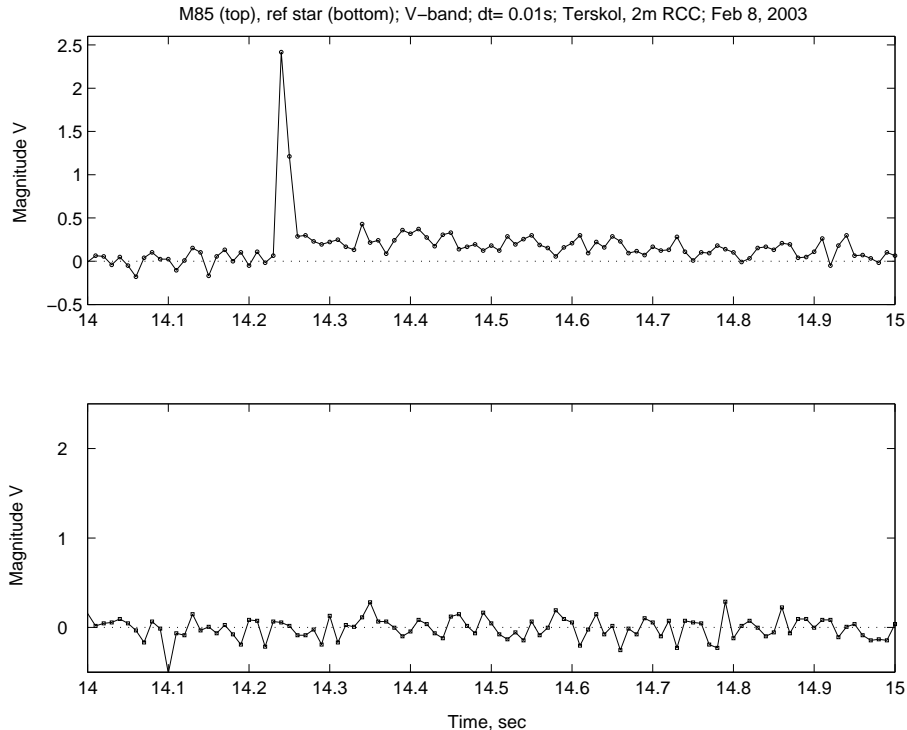


Figure 1. Fragments of V-band light curves the galaxy M85 (top) and a reference star (bottom) as seen simultaneously by the Terskol 2-m telescope on 2003 February 8, 02:05:22 UT (max).

Figure 2 shows that the coincidence technique may lead to a substantial gain in detection of small-scale variability. The flare event at 85 sec is defined by the individual confidence probability of 99.999497 and 99.942578 percent, respectively. Its joint confidence probability, which was defined in equation (2), goes up to 99.999994 percent with two telescopes operating synchronously. The frequency of occurrence of such an event is equal to 0.000275 for a record of 38 minutes and sampling frequency of 2 Hz. It means that one should perform on the average 3636 similar tests of 38 min duration each, that is, 96 days in total, to obtain the same result on account of random fluctuations. Thus we argue that the flare event is a real phenomenon.

### 3. Discussion and Conclusions

There is a growing evidence for the existence of intermediate-mass black holes in the mass range  $\sim 10^2\text{--}10^4 M_\odot$ , especially in dense globular clusters (Miller 2003). These are undergoing frequent coalescence with stellar-mass black holes as well as normal stars. Stars whose orbits cross the event horizon or the tidal disruption radius of a black hole are destroyed before they complete the orbit (Alexander et al. 2003). The Keplerian orbital period for a black hole of mass  $M$  in a vicinity of the event horizon is  $P \approx 10^{-5} (M/M_\odot)$  s. Thus, orbital inspiral

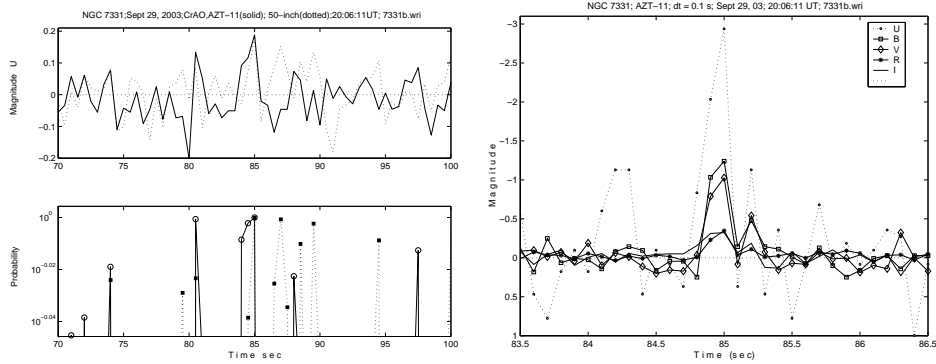


Figure 2. Left side: The light curves of NGC 7331 from the Crimean AZT-11 (solid) and 50-inch (dotted) telescopes (upper panel) with a sampling time 0.5 s and their cumulative probability functions (lower panel) on September 29, 2003, 20:06:11 UT. Right side: Fragments of NGC 7331 light curves in the UBVRI bands with a sampling time 0.1 s.

into a supermassive black hole in a galactic center may be a strong source of gravitational radiation (and optical emission as well) on timescales of  $10^{-10}$ – $10^5$  s. In the case of intermediate-mass black holes, this timescale is in the range 1–100 ms.

We adopt the luminosity of M 85 to be  $3 \times 10^{43} \text{ erg s}^{-1}$  (a typical value). Then the M 85 flare event has energy  $1.3 \times 10^{42} \text{ erg s}^{-1}$  in the V band. We may estimate the mass of a compact object to be  $\sim 1000 M_{\odot}$ , if the duration of the M 85 flare event is defined by the orbital inspiral into a black hole. The NGC 7331 flare event has a peak power value  $\sim 3.3 \times 10^{42} \text{ erg s}^{-1}$  in the B band, close to that of the M 85 flare event. Merging of intermediate-mass black holes with small black holes or normal stars in galactic nuclei and globular clusters seems to be the most plausible mechanism for short bursts. As shown by Misner et al. (1973), during the merger the output in gravitation waves may reach  $10^{51}$ – $10^{56} \text{ erg s}^{-1}$ ; in electromagnetic waves, the luminosity may be many orders of magnitude less.

To summarize, our observations support the hypothesis that intermediate-mass black holes exist in the centers of galaxies and dense globular clusters.

## References

- Alexander, T. & Hopman, C. 2003, *ApJ*, 590, L29
- Allen, C.W. 1973, *Astrophysical Quantities*, 3rd ed., (Athlone Press: London), p. 156
- Astone, P., Babusci, D. & Bassan M. 2002, *Class. Quantum Grav*, 19, 5449
- Byrne, P.B., & Wayman, P.A. 1975, *MNRAS*, 173, 537
- Fisher, R.A. 1970, *Statistical Methods for Research Workers*, Fourteenth edition, (Macmillan)
- Miller, M.C. 2004, in *Probing General Relativity with Mergers of Supermassive and Intermediate-Mass Black Holes*, AAS High Energy Division, 8
- Misner, C.W., Thorne K.S. & Wheeler J.A. 1973, *Gravitation*, (W.H.Freeman and Company)
- Zhilyaev, B.E., Romanyuk Ya.O. & Svyatogorov, O.A. 2003, *Baltic Astronomy*, 12, 561